

The University of Chicago

THE ABSORPTION OF THE SHOWER-PRODUCING
COMPONENT OF COSMIC RADIATION IN
IRON AND LEAD

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

DEPARTMENT OF PHYSICS

1939

By
JOSIAH CRUDUP

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

Reprinted from
THE PHYSICAL REVIEW
Vol. 54, No. 7, October 1, 1938

The University of Chicago

THE ABSORPTION OF THE SHOWER-PRODUCING
COMPONENT OF COSMIC RADIATION IN
IRON AND LEAD

A DISSERTATION SUBMITTED TO THE FACULTY
OF THE DIVISION OF THE PHYSICAL SCIENCES
IN CANDIDACY FOR THE DEGREE OF DOCTOR OF
PHILOSOPHY

DEPARTMENT OF PHYSICS

1939

By
JOSIAH CRUDUP

Private Edition, Distributed by
THE UNIVERSITY OF CHICAGO LIBRARIES
CHICAGO, ILLINOIS

Reprinted from
THE PHYSICAL REVIEW
Vol. 54, No. 7, October 1, 1938



The Absorption of the Shower-Producing Component of Cosmic Radiation in Iron and Lead

JOSIAH CRUDUP

Ryerson Laboratory, University of Chicago, Chicago, Illinois

(Received August 3, 1938)

Measurements of the absorption coefficient of the shower-producing component of primary cosmic radiation give 0.35 cm^{-1} in lead and 0.076 cm^{-1} in iron. The atomic absorption coefficients corresponding to these values are nearly in direct proportion to the squares of the atomic numbers of the absorbing materials. The value 0.35 cm^{-1} for lead agrees rather well with that found by Woodward. A slight minimum was found in the curve of the absorp-

tion for lead at a point between 8 and 10 cm, confirming similar findings by Rossi and others. No minimum was found in the absorption curve for iron up to a thickness of 20 cm. For the rays received within a given solid angle, the ratio of the shower rate to the vertical coincidence rate falls from 5.1 percent with no shield to 2.6 percent with 15 cm of lead, and to 3.0 percent with 20 cm of iron.

IT is well recognized that most of the electron showers associated with cosmic rays at sea level are produced by a non-ionizing type of radiation. These non-ionizing shower-producing rays very probably consist of photons, which are in turn excited by primary shower-producing particles that may be electrons. The terms *A*, *B*, and *C* will be applied, respectively, to the primary shower-producing particles, the shower-producing photons, and the shower electrons. The present paper is concerned chiefly with a measurement of the absorption coefficient in iron and lead of rays of type *A*, i.e., the primary shower-producing component of cosmic radiation. A measurement is also made of the relative number of showers and vertical coincidences.

Measurements designed for the same purpose have been performed by Sawyer,¹ Rossi,² Woodward,³ and others. The present experiment has

followed Sawyer's procedure of studying showers (*C*-rays) that are produced in a material that differs from the one in which the shower-producing radiation *B* itself is excited. Since with this technique the rays of types *B* and *C* are always produced in the same substance, a direct comparison is obtained of the absorption of the primary shower-producing radiation *A* in various absorbing materials. We have replaced the triangular arrangement of three counters used by Sawyer¹ with the fourfold coincidence arrangement of counters shown in Fig. 1. Thus not only is the number of chance counts reduced, but it also becomes necessary for all of the primary rays to pass through the absorbing materials before producing rays which affect the counters.

EXPERIMENTAL PROCEDURE

With the arrangement of counter tubes shown in Fig. 1 coincidence counts are possible only when showers are produced in the lead scatterer *S*, except for the very rare shower particles which

¹ J. H. Sawyer, *Phys. Rev.* **50**, 25 (1936).

² B. Rossi, *Zeits. f. Physik* **82**, 151 (1933).

³ R. H. Woodward, *Phys. Rev.* **49**, 711 (1936).

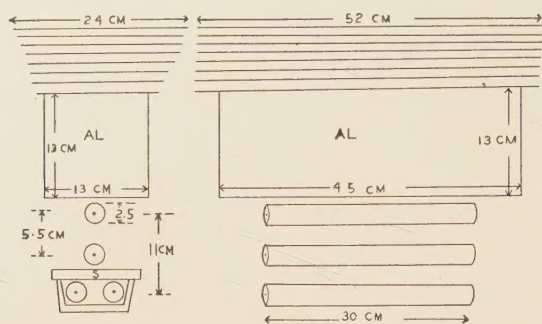


FIG. 1. Arrangement of apparatus in end and side view.

may be able to penetrate 1 cm of lead. Our experiments indicate that the aluminum block placed above the tubes is thick enough to absorb nearly all of the *B*-type rays entering from above. Thus all of the *B*-rays which strike the scatterer *S* are produced in the aluminum block. Above the aluminum block are placed the plates of lead or iron, whose absorption of the *A*-type of radiation is to be measured. In order to reduce disturbing effects from showers excited in matter in the neighborhood, the apparatus is used under canvass on the roof of Ryerson Laboratory.

The Geiger-Müller tubes are filled with hydrogen to a pressure of 9.6 cm of mercury, and about 0.2 cm of dry air. The center of the plateau of voltage operation is about 1220 volts. Each tube is wrapped in a thin aluminum foil which is grounded. The source of high voltage placed across the counter tubes is a modification of the arrangement given by Street and Johnson.⁴ The circuit used with the Geiger-Müller tubes is approximately described by Neher and Harper.⁵

Figure 2 shows in curves *A* and *B* the counting rates observed for various thicknesses of iron and lead, respectively. Each datum point represents some thirty hours of readings and the length of the vertical line at each point represents the standard deviation as calculated from the number of counts. Repeated observations at widely separated intervals showed experimental deviations consistent with those to be expected by this statistical calculation. This may be taken as sufficient test of the consistency of the readings.

⁴ J. C. Street and T. H. Johnson, J. Frank. Inst. 214, 155 (1932).

⁵ H. V. Neher and W. W. Harper, Phys. Rev. 49, 940 (1936).

Except for the last two points of curve *B*, the data may be represented with sufficient accuracy by the empirical expression

$$N = N_0 e^{-\mu x} + C. \quad (1)$$

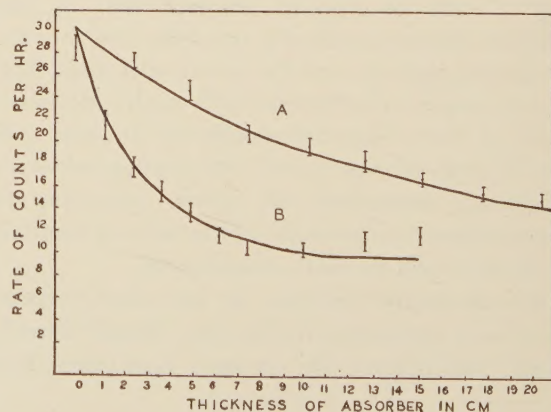
The smooth curves in Fig. 2 have been plotted with the values $N_0 = 20$, $C = 10$, $\mu_{Fe} = 0.076 \text{ cm}^{-1}$, $\mu_{Pb} = 0.35 \text{ cm}^{-1}$.

INTERPRETATION

If we assume that the primary cosmic rays *A* are electrons of an absorption coefficient (μ_1), the secondary rays *B* are photons of an absorption coefficient (μ_2), and the tertiary rays *C* are shower particles of an absorption coefficient (μ_3), it can be shown that the counting rate *N* should be given by the following equation.

$$N = \frac{C}{(\mu_3 - \mu_1)(\mu_2 - \mu_1)} \times \left\{ e^{-\mu_1 x} - \frac{(\mu_3 - \mu_1)}{(\mu_3 - \mu_2)} e^{-\mu_2 x} + \frac{(\mu_2 - \mu_1)}{(\mu_3 - \mu_2)} e^{-\mu_3 x} \right\}. \quad (2)$$

The curve shown in Fig. 3 is plotted with the values $\mu_1 = 0.3 \text{ cm}^{-1}$, $\mu_2 = 0.7 \text{ cm}^{-1}$, $\mu_3 = 5.0 \text{ cm}^{-1}$ of lead. The shape of the portion *AB* of this curve is determined primarily by the coefficient μ_3 , the portion *BC* by the coefficient μ_2 , and from *C* to *D* by the coefficient μ_1 . The fact that the data shown in Fig. 2 are on the downward sloping part of the curve thus indicates that the aluminum block is adequate to absorb most of the secondary photons that come from above. This in

FIG. 2. Counting rates as functions of thickness of iron (curve *A*) and of lead (curve *B*).

turn gives assurance that *B*-type rays reaching the scatterer *S* are those produced in the aluminum block. Thus we may provisionally identify the absorption coefficient measured by the arrangement of Fig. 1 with the absorption coefficient of the primary shower-producing particles *A* in iron and lead.

The constant *C* is due at least in part to the showers produced in the air and in the wood structure placed above the tubes to support the iron and lead. It is noteworthy, however, that the data associated with curve *B* show a minimum at about 9 cm of lead. This result confirms similar findings by Rossi⁶ and others. It is not impossible that the rise beyond 9 cm of lead may represent the excitation of a penetrating cosmic ray by a less penetrating primary ray.⁷ In this case the rising datum points at the end of curve *B* should correspond to the portion of the curve of Fig. 3 lying between *B* and *C*. The base line of curve *B* should then not have the constant value $C=10$, but should rather be sloping upward from the origin. In view of the speculative character of this hypothesis, we preferred to use the simpler assumption represented by Eq. (1). Had the alternative of an upward sloping base line been taken, the value of N_0 would have been increased by roughly fifty percent. The value of μ , however, would not have been greatly altered.

On the basis of the relative absorption in iron

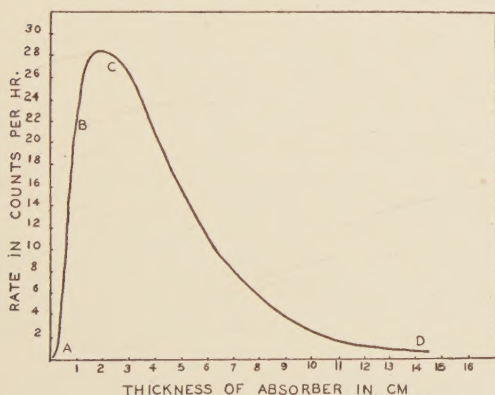


FIG. 3. Theoretical curve, plotted according to Eq. (2), for the variation of counting rate with absorber thickness.

⁶ B. Rossi, *International Conference on Physics* (London, 1934).

⁷ Thus, Heitler, *Proc. Roy. Soc.*, June, 1938, suggests that the primary electrons may excite alternatively penetrating barytrons or less penetrating electron pairs through the medium of secondary photons.

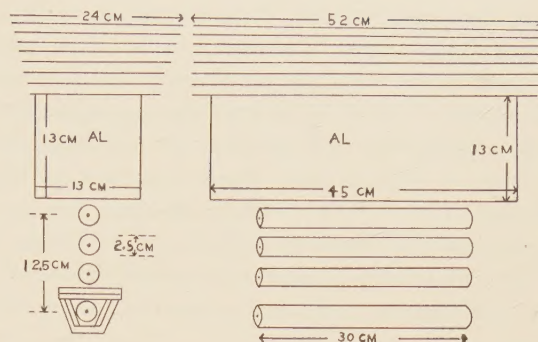


FIG. 4. Arrangement of apparatus to determine ratio of shower-producing rays to the total vertical cone of cosmic rays.

and lead we should not expect a similar minimum in curve *A* until a thickness of 35 to 45 cm of iron is reached. This is in accord with the observed absence of such a minimum in the data for iron, and indicates the importance of using great thicknesses of absorber for measuring this highly penetrating secondary radiation.

The value of μ required for the empirical formula (1) should thus differ little from the true absorption coefficient of the primary shower-producing ray in iron and lead. The atomic absorption coefficients corresponding to the values of $\mu_{Pb}=0.35 \text{ cm}^{-1}$ and $\mu_{Fe}=0.076 \text{ cm}^{-1}$ are, respectively, 1.05×10^{-23} and 0.08×10^{-23} . These values for lead and iron are approximately in direct proportion to the squares of the atomic numbers of the absorbing materials. This result does not agree with that found by Sawyer.¹ The value for the absorption in lead is in good agreement with the corresponding value of 0.33 cm^{-1} found by Woodward.³

THE RELATIVE NUMBER OF SHOWER-PRODUCING RAYS

A rough estimate of the ratio of shower-producing rays to the total vertical cone of cosmic rays was made possible by counting the coincidence rate with four counters in line as shown in Fig. 4. With no absorber above the aluminum block the observed rate of shower coincidence was 11.7 percent as great as that of the observed vertical coincidence. Because, however, of the greater separation of the tubes in vertical arrangement, the solid angle of the vertical cone was less than in the shower arrange-

ment by a factor of 2.3. Thus for the rays within a given solid angle the shower rate is 5.1 percent as great as the vertical coincidence rate. For the full shield of 15.24 cm of lead the corresponding ratio is reduced to 2.6 percent, and for 20.48 cm of iron to 3.0 percent. These fractions of the primary rays which produce showers are approximately the same as those found by Geiger.⁸

The ratio of the number of recorded showers to the total number produced somewhere along the

path of the primary shower-producing rays is unknown. The smaller percentage of the observed showers suggests, however, that the shower-producing component constitutes the smaller part of the primary cosmic radiation.

It gives me great pleasure to acknowledge my indebtedness to Professor A. H. Compton for his constant inspiration and helpful advice throughout this investigation. I wish also to express my sincere appreciation to the General Education Board for the fellowship aid given to me during this time.

⁸ H. Geiger, *Zeits. f. Physik* 97, 300 (1935).



Digitized by the Internet Archive
in 2026

https://archive.org/details/IA41533920_0111

